Laser etching GaN materials under various atmosphere conditions

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Abstract

A study of laser processing of gallium nitride (GaN) material is reported. The GaN film samples used in this experiment are grown on sapphire by either hydride vapor phase epitaxy (HVPE) or metalorganic chemical vapor deposition (MOCVD) method. A pulsed KrF excimer laser at 248 nm with 20 nsec pulse width and 1 Hz repetition rate is used to etch the GaN film. Both pulse energy and number of pulses were varied to establish the material etching parameters under different environmental conditions. By changing the pulsed energy at constant pulse numbers, ablation of GaN surface was observed at threshold laser fluence of 0.3 J/cm^2. Laser etching increase with reducing environment pressure. At 1.0 J/cm^2 laser fluence, the etching rate is about 35 nm/pulse at atmosphere pressure and increases to 60 nm/pulse at low pressure of 10^{-6} torr. The etched depth also increases with increasing laser fluence. By changing the number of pulses at fixed laser fluence of 3.75 J/cm^2, the etched depth increases linearly with the number of laser etching pulses. The surface morphology of the etched surface was investigated by atomic force microscope (AFM) and secondary electron emission (SEM) techniques. These results show a relatively smooth vertical etched surface was observed.

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Summary

The GaN-based wide band gap semiconductor is one of the most promising materials for blue light emitting diodes and diode lasers. One of the major challenges to build these high performance devices is the processing of GaN. Due to the rare chemical stability and high hardness of GaN, certain proper etching method is required. So far, various processing techniques for dry etching have been reported. These reports include plasma etching, reactive ion etching (RIE), electron cyclotron resonance, inductively coupled plasma, magnetron RIE, chemically assisted ion beam etching and reactive ion beam etching[1]. Recently, photoassisted dry etching and laser etching of GaN materials[2-6] were also reported. The reported laser etching for GaN materials showed good etched surface morphology and high etching rate of 50-140 nm/pulse. However, there are few reports on the effect of etching rate under different pressure conditions. In this paper, we report the etching of GaN materials using KrF excimer laser and establish the threshold laser fluence as well as etching rates under various etching conditions.

Two GaN film samples were used for the experiment. One sample has film thickness of 2.5 μm grown on sapphire substrate by MOCVD. Another sample with 14.9 μm thick was also grown on sapphire substrate by HVPE. The effect of laser etching environment condition on laser fluence and etching rate were investigated using the 2.5 μm thick sample under three pressure conditions: one atmosphere pressure, 10^{-3} torr and 10^{-6} torr. The sample after laser etching tends to show some material residues such as Ga, Ga oxide. These residues were clean by dilute acid solution such as HCl or H_2SO_4/H_2O_2 before measurement of etched depth. The laser fluence was varied from 0.2 to 1.0 J/cm^2 at constant number of pulses. Figure 1 shows the etching rate as a function of laser fluence for the three different pressure conditions. In all conditions, etching rate increase with increasing laser fluence as expected with high etching rate for low-pressure condition. The etching rate is about 35 nm/pulse in one atmosphere pressure and is about 60 nm/pulse at 10^{-3} and 10^{-6} torr at the incident laser fluence of 1.0 J/cm^2. The threshold laser fluence from these results also show near similar value of 0.3 J/cm^2. The higher etching rate in low-pressure can be used for processing that requires high etching rate. To obtain a higher etching rate, we studied the dependence of the etched depth on the numbers of pulses at fixed laser fluence of 3.75 J/cm^2. The sample with 14.9 μm thick was etched under atmosphere condition with different number of pulses. Figure 2 shows the etched depths as a function of pulse numbers. The etched depth increases linearly with the numbers of pulses. This dependence is similar to the reported elsewhere[6]. Form this data, the higher etching rate as high as 82 nm/pulse was obtained at increased laser fluence. Figure 3 shows a SEM picture of the etched sidewall.

The etched surface morphology was also obtained by AFM measurement in contact mode operation with a scan area of 5 μm^2. Figure 4 shows the root mean square (RMS) roughness as a function of numbers of pulses. The root mean square (RMS) roughness is around 4~14 nm. These results show the relatively better etched surface morphology was obtained under the atmosphere pressure condition.

In conclusion, we investigated the KrF excimer laser etching of GaN materials under various conditions. The threshold laser fluence for laser etching of GaN was 0.3 J/cm^2 under different pressure conditions. At low laser fluence of 1.0 J/cm^2, the etching rate of 60 nm/pulse under low-pressure condition and 35 nm/pulse under atmosphere pressure condition were obtained. Higher etching rate of 82 nm/pulse was achieved at high laser fluence of 3.75 J/cm^2 under atmosphere pressure. The laser etching processing seems to be a viable GaN etching technique, especially for high speed-deep etching.

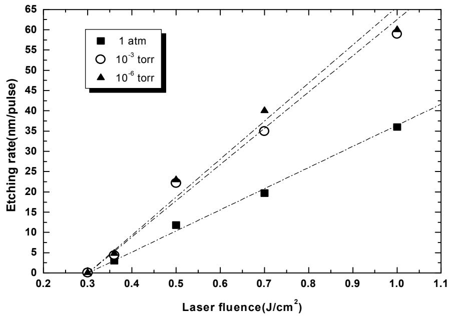

Fig.1. The dependence of etched rate on laser fluence under different pressure conditions.

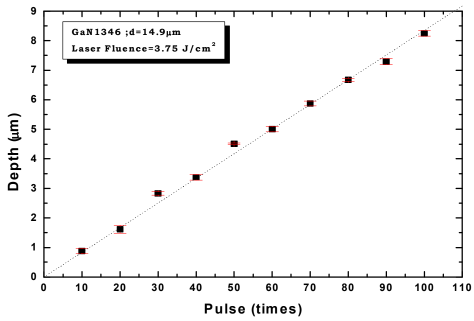

Fig.2. The dependence of etched depth on the number of pulses.

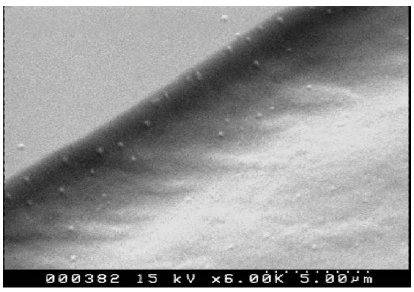

Fig.3. SEM micrograph of GaN etched by excimer laser.

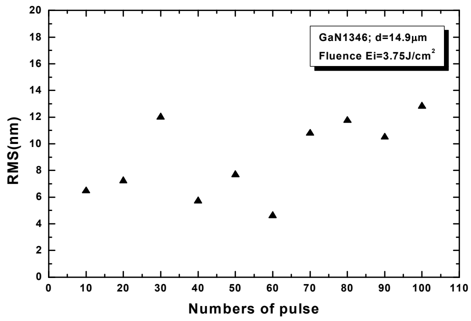

Fig.4. The root mean square roughness as a function of numbers of pulse.

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